New Magnetic Materials
J. F. Herbst, Chairman

Mössbauer effect and electronic transport studies of icosahedral
Al\textsubscript{50}Pd\textsubscript{10}Mn\textsubscript{25-x}Fe\textsubscript{x}B\textsubscript{15} alloys

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The temperature and applied magnetic field dependence of the resistivity of icosahedral
Al\textsubscript{50}Pd\textsubscript{10}Mn\textsubscript{25-x}Fe\textsubscript{x}B\textsubscript{15} \(x=0\) and 5 \) alloys has been measured between 4.2 and 300 K. At low temperature, \(T<30\) K, the resistivity showed a rapid decrease with increasing temperature and may be described by a combination of weak localization (WL) and magnetic scattering effects. At higher temperatures the resistivity is adequately described by the temperature dependence of the structural and magnetic effects as described by Boltzmann-type transport. The measured magnetoresistance of both samples is consistent with theoretical predictions based on WL. The room temperature Mössbauer effect spectrum of the \(x=5\) sample showed a well resolved doublet with mean isomer shift (relative to room temperature \(\alpha\)-Fe) and quadrupole splitting of +0.22 mm/s and 0.36 mm/s, respectively. These results indicate that the Fe probe nuclei do not carry a magnetic moment in these alloys. © 1996 American Institute of Physics. [S0021-8979(96)16508-0]

I. INTRODUCTION

Quasicrystalline (QC) alloys which contain Mn have shown a wide variety of magnetic behavior and, in some cases have exhibited varying degrees of magnetic order. Typically, these magnetically ordered materials have been characterized by small Mn magnetic moments and low Curie temperatures. Recently, alloys which exhibit high Curie temperatures and substantial Mn moments have been reported\textsuperscript{1-5} in the Al-Mn-Pd-B system. The availability of these materials allows for the investigation of the relationship of magnetic order and quasicrystallinity. In the present work we report on magnetotransport and Mössbauer effect studies of Al\textsubscript{50}Pd\textsubscript{10}Mn\textsubscript{25-x}Fe\textsubscript{x}B\textsubscript{15} alloys.

II. EXPERIMENTAL METHODS

Samples of Al\textsubscript{50}Pd\textsubscript{10}Mn\textsubscript{25-x}Fe\textsubscript{x}B\textsubscript{15} \(x=0\) and 5 \) were prepared by melt spinning. Resulting ribbons were shown to be single phase icosahedral quasicrystals by x-ray diffraction studies. The transverse magnetoresistance was measured at temperatures from 4.2 to 300 K in applied fields up to 5.5 T. The room temperature \(^{57}\text{Fe}\) Mössbauer effect spectrum of the \(x=5\) sample was obtained using a conventional constant acceleration drive system.

III. RESULTS AND DISCUSSION

The magnetoresistance data of Al\textsubscript{50}Pd\textsubscript{10}Mn\textsubscript{25-x}Fe\textsubscript{5} QC alloys \(x=0,5\) are shown in Fig. 1. The most general expression for the magnetoresistance, \(\Delta\rho(B)\), due to Fukuyama and Hoshino\textsuperscript{8} which includes the effects of spin-orbit scattering, Zeeman splitting, and magnetic impurities is given by:

\[
\Delta\rho = \rho A \sqrt{eB \frac{A}{h}} \left[ \frac{1}{2} \left( \frac{B}{B_{t}} - \frac{B}{B_{s}} \right) f_{2}(\frac{B}{B_{t}}) - f_{3}(\frac{B}{B_{t}}) \right] - f_{3}(\frac{B}{B_{2}})
\]

\[
- \sqrt{\frac{A B_{s0}}{3 B}} \left( \frac{\sqrt{t_{r}} - \sqrt{t_{f}}}{\sqrt{1 - \gamma}} + \sqrt{t_{r}} - \sqrt{t_{f} + 1} \right)
\]

where

\[
A = \frac{e^{2}}{2\pi^{2}h},
\]

\[
\gamma = \frac{3g^{*}\mu_{B}B}{8eD(B_{s0} - B_{s})},
\]

\[
B_{\phi} = B_{1} + 2B_{2},
\]

\[
B_{s} = B_{1} + \frac{1}{3}B_{1} + \frac{1}{3}B_{s0},
\]

\[
t = \frac{3B_{\phi}}{4(B_{s0} - B_{s})},
\]

\[
B_{\pm} = B_{\phi} + \frac{1}{2}(B_{s0} - B_{s})(1 \pm \sqrt{1 - \gamma}) + 2B_{s},
\]

\[
t_{\pm} = t \pm \frac{1}{2}(1 \pm \sqrt{1 - \gamma}).
\]

![Image](image-url)

FIG. 1. The magnetoresistivity at 4.2 K of Al\textsubscript{50}Pd\textsubscript{10}Mn\textsubscript{25-x}Fe\textsubscript{5} plotted as a function of \(B\). The solid lines are fits to WL theory.
and $D$ is the diffusion coefficient. The characteristic fields are related to electron scattering times through relations of the type
\begin{equation}
B_x = \frac{\hbar}{4eDt_x},
\end{equation}
where $x=i, s$, and $t$ refer to the inelastic, spin-orbit, and magnetic spin-flip scattering times, respectively. The Kawai-bata function, $f_3(x)$, has been written in the form proposed by Baxter et al.,
\begin{equation}
f_3(x) = 2\left(\sqrt{2 + \frac{1}{x}} - \sqrt{\frac{1}{x}}\right) - \left(\frac{1}{2} + \frac{1}{x}\right)^{-1/2}
+ \left[\frac{3}{2} + \frac{1}{x}\right]^{-1/2}
+ \frac{1}{48} \left(2.03 + \frac{1}{x}\right)^{-3/2}.
\end{equation}

The magnetoresistance due to weak localization, $\Delta\rho_{\text{WL}}$, as given by Eq. (1), is negative in the case of weak spin-orbit scattering systems, i.e., $\tau_s<\tau_{so}$. In the case of strong spin-orbit scattering systems the magnetoresistance is positive and $\tau_i>\tau_{so}$.

The fitting procedure adopted for the samples studied is as follows. The WL contribution to the magnetoresistance is fitted with the temperature-dependent inelastic scattering time $\tau_i(T)$, and the temperature independent scattering times $\tau_{so}$ and $\tau_s$ as free parameters. The diffusion coefficient is taken to be 0.075 cm² s⁻¹ from literature values for similar quasicrystals. Quantum corrections to the resistivity predict $\Delta\rho/\rho_{\text{WL}}=\rho$. Using $\rho$ as a free parameter in the WL expression allows for a determination of the resistivity in a way that is independent of the sample geometry.

The agreement between WL theory and the experimental data is good over the entire range of fields as illustrated by the fits shown in Fig. 1. The magnetoresistance of $x=0$ sample is positive in region $B<2.5$ T followed by a negative magnetoresistance in the remaining range of field. This feature reflects the moderate spin-orbit scattering case in which $\tau_i=\tau_{so}$. For the $x=5$, the magnetoresistance is totally negative and reflects the presence of weak spin-orbit scattering, $\tau_s<\tau_{so}$. The value of the fitted parameters are given in Table I.

The temperature dependence of the resistivity is illustrated in Fig. 2. The resistivity of the Al₇₀₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋_-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+ TABLE I. Fitted parameters values for Al₇₀₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋_-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+ | Alloy (x) | 1/τᵢ₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋_-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+ | | (×10⁹ s⁻¹) | (×10⁹ s⁻¹) | (×10⁹ s⁻¹) | (μΩ cm) | (μΩ cm) |
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</table>

FIG. 2. Temperature dependence of the electrical resistivity normalized to the value at 4.2 K for Al₇₀₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋_-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+ FIG. 3. Room temperature ⁵⁷Fe Mössbauer effect spectrum of icosahedral Al₅₀₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋₋_-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+ J. Appl. Phys., Vol. 79, No. 8, 15 April 1996 Yewondwossen et al.
Mössbauer spectra in terms of two discrete sites is illustrated in Fig. 3 and are summarized in Table II. In this case the two doublets have been chosen to have similar isomer shifts. Mean quadrupole parameters are consistent with Mössbauer effect results obtained for similar QCs. Spectra have also been fitted on the basis of a combined Zeeman and quadrupole interaction. The quality of fit for this analysis did not show any improvement over the previous analysis, suggesting that the Fe probe atoms do not carry magnetic moments in these alloys. There has been considerable work on Fe moments formation in QCs and evidence seems to suggest that Fe atoms prefer to reside in sites where a moment does not form.\textsuperscript{14,19} The present measurements are consistent with this picture.

IV. CONCLUSIONS

The temperature and applied magnetic field dependence of the resistivity of icosahedral Al\textsubscript{50}Pd\textsubscript{10}Mn\textsubscript{25−x}Fe\textsubscript{x}B\textsubscript{15} (\textit{x} = 0 and 5) alloys has been measured. At low temperature results may be explained by a combination of weak localization and Kondo-type magnetic scattering effects. At higher temperatures the resistivity is adequately described by the temperature dependence of Boltzmann-type transport. The room temperature Mössbauer effect spectrum of the \textit{x} = 5 sample showed a well resolved doublet. A goodness-of-fit analysis indicated that the spectrum was appropriately described by a combination of two symmetric quadrupole doublets rather than an analysis based on the presence of a Zeeman splitting. This analysis suggests that the Fe probe atoms prefer to reside in sites where they do not carry a magnetic moment.

ACKNOWLEDGMENTS

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\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
   & \(\Delta\) (mm/s) & \(\delta\) (mm/s) \\
\hline
doublet No. 1 & 0.233 & +0.219 \\
doublet No. 2 & 0.493 & +0.230 \\
mean value & 0.362 & +0.224 \\
\hline
\end{tabular}
\caption{Room temperature \textsuperscript{57}Fe Mössbauer effect parameters for the spectrum of icosahedral Al\textsubscript{50}Pd\textsubscript{10}Mn\textsubscript{25−x}Fe\textsubscript{x}B\textsubscript{15}. Quadrupole splittings, \(\Delta\), and isomer shifts, \(\delta\), relative to \(\alpha\)-Fe are given for the two doublets as described in the text. Mean parameter values are also given.}
\end{table}